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Effects of Changes in the Ozone in the Stratosphere Upon Animals, Crops, and Other Plant Life

A Report to the Congress

by the

U.S. Department of Agriculture

Pursuant to

Section 154, Subsection (d) P.L. 95-95

Prepared by
The Agricultural Research Service
December 1977

EXECUTIVE SUMMARY

The U.S. Department of Agriculture was asked to organic and manage a research program dealing with the potential hazards of ultraviolet (UV) radiation reaching the earth's surface as a result of stratospheric ozone depletion. Considerable progress has been made in understanding the biological impact of UV-B (*radiation in the biologically active region of 280-320 nm) on terrestrial plants and animals. Much additional research is necessary, however, before an assessment can be made of the potential impact of stratospheric ozone reduction on agriculturally important and native species of plants and animals.

Major accomplishments resulting from biological research program are as follows:

1. Substantially all major crops, including many horticultural species and varieties, and some native species have been screened for sensitivity to increased levels of UV-B.

2. Injury threshold levels were found to vary widely among species and within cultivars and varieties of the same species.

3. It was almost universally observed that field grown plants were more tolerant to enhanced UV-B levels than were the identical selections grown in greenhouses or controlled environment chambers. A seasonal difference in sensitivity to enhanced levels of UV-B was also observed, with plants showing greater tolerance during the summer months.

4. Some economic plant species, such as cantalope and cotton, have been shown to be sensitive to present levels of UV-B reaching the earth's surface.

5. Highly pigmented insects, especially those with a high melanin content, were found to be highly resistant to UV-B. Honeybees, for example, were unaffected by very high levels of UV-B. Some leaf disease organisms display similar responses.

6. We have established that cancer eye may have been induced in Hereford cattle by high levels of UV-B.

In the Biological and Climatic Effects Research (BACER) program, as with the Climatic Impact Assessment Program (CIAP), UV enhancement research is dependent on UV-emitting fluorescent lamps. Use of these lamps create two special problems which were inadequately addressed in the CIAP program primarily because the equipment for measuring UV-B radiation was inadequate. These problems have been, in a large measure, solved by instruments designed by the Agricultural Research Service (ARS) thus permitting us to address the lamp problems.

First, the spectral characteristics of the lamps available for UV research do not simulate the sun's spectral characteristics, requiring that an acceptable correction factor be used for accurate interpretation of observed biological response. Considerable progress has been made towards defining this correction factor as related to the growth and development of higher plants.

Second, energy emitted by a fluorescent lamp and falling on a horizontal surface parallel to the long axis of the lamp is unequal as it is highest directly under the center of the lamp and falls off rapidly in all directions from the center. By using the improved instrumentation and through development of equations defining this energy variable, careful energy-defined biological research has been accomplished.

Another major problem still not adequately resolved is the variation in the sun's UV irradiance as a function of latitude and land elevation, and the sun's variability from day to day as the result of stratospheric and atmospheric changes. To define properly what energy levels produce a few percentage points increase in UV-B, some carefully defined sun energy spectrum must be available as a base from which to calculate enhancement. This sun spectral radiant power need not be identical for all U.S. locations. Continued monitoring of UV solar spectral irradiance at selected locations is necessary before biological response to enhanced UV-B reaching the earth's surface can be accurately predicted.

The Department recommends that there be continuing research to investigate the responses of plants and animals to increased levels of ultraviolet radiation resulting from changes in stratospheric ozone concentrations alleged to be caused by release of chlorofluoromethanes, nitrogen oxides, and perhaps other substances.

INTRODUCTION

In 1972, Congress requested the U.S. Department of Transportation to determine whether or not fleet operation of SST aircraft could be expected to induce environmental degradation. This resulted in the establishment of the Climatic Impact Assessment Program (CIAP) to evaluate existing data and initiate new research programs to meet the Congressional mandate. The U.S. Department of Agriculture was asked by the Department of Transportation to manage and organize that portion of the research program dealing with the potential hazards to higher terrestrial plants of increased ultraviolet radiation reaching the earth's surface as the result of stratospheric ozone depletion. Emphasis was placed on economically important species. This research effort, culminating in 1975, involved Agricultural Research Service (ARS) scientists at several locations, including Beltsville, Maryland, Gainesville, Florida, and State College, Mississippi. Also involved were scientists at the University of Florida and Utah State University under ARS contractual research. Results were published in the Department of Transportation Climatic Impact Assessment Program Monograph 5, Part 1 (DOT-TST-75-55), (1975).

This research provided a scientific base of data, manpower, and specialized equipment for the more recent program involving the potential hazard from release of chlorofluoromethane (CFM) and other potential reactants with stratospheric ozone.

In response to growing Congressional, scientific, and public concern on the possible biological and climatic impact of stratospheric ozone reduction that might be caused by CFM's and other man-made contaminants, the White House in January 1975 established the Interagency Task Force on Inadvertent Modification of the Stratosphere (IMOS) under the co-chairmanship of the Council on Environmental Quality (CEQ) and the Federal Council for Science and Technology (FCST).

An ARS scientist, Dr. Donald T. Krizek, was appointed as USDA representative to this interagency group. In addition, he was designated to chair a USDA Working Group on Ozone Depletion in the Stratosphere. This group was assigned the responsibility for developing USDA research proposals for assessing the magnitude of the problem and preparing a report describing current knowledge, on-going research programs, and critical research needs on the biological effects of increased ultraviolet radiation. Special emphasis was placed on the biologically active region 280-320 nm (UV-B). The USDA input appeared as a chapter in the IMOS Report entitled, "Fluorocarbons and the Environment", (June 1975).

Because of growing concern by IMOS and the Interdepartmental Committee for Atmospheric Sciences (ICAS) over the inadequacy of the Federal program to answer questions crucial to regulatory decision-making on fluorocarbons in November 1975, the ARS representative to IMOS was asked to organize and chair an IMOS Subcommittee on Biological and Climatic Effects Research (IMOS/BACER). Following a briefing which the ARS representative and the co-chairman of IMOS held with the President's Science Advisor and the other members of the FCST in

December 1975, he was asked to develop a comprehensive report for an interagency research program to assess the biological and climatic effects of stratospheric ozone reduction caused by inadvertent release of man-made contaminants. The final report entitled, "A Proposed Federal Research Program to Determine the Biological and Climatic Effects of Stratospheric Ozone Reduction," (IMOS/BACER Report) was released by FCST in February 1976. In anticipation of pending legislation on regulation of CFM's, the Environmental Protection Agency (EPA) was asked by FCST to serve as lead agency for a short-term research program to implement the recommendations made in the IMOS/BACER Report.

In June 1976, ARS was asked to chair an interagency task group on Biological (Non-Human) Effects Research with responsibility for refining the research agenda spelled out in the IMOS/BACER Report and for developing a short-term research program that might answer key questions within a one-year time frame to serve as a basis for possible regulatory decisions on CFM required by EPA in the spring of 1978. These recommendations were transmitted to EPA along with other Task Group recommendations and partially formed the basis of the $4 million interagency BACER program funded by EPA in FY 1977. Approximately $1 million of this amount was transferred to ARS on pass-through funds for in-house and extramural research on the effects of increased UV-B radiation on terrestrial organisms including farm animals, insects, and plants. In addition, ARS Funds were also committed to this effort. Some of this resulted from redirection of funds from other ARS research programs. The Administrator of ARS also provided some additional funds from his reserve to expedite this effort. In-house research during FY 77 was conducted by ARS at Beltsville, Maryland (Agricultural Equipment Laboratory, L. E. Campbell; Chemical and Biophysical Control Laboratory, D. K. Hayes; Instrumentation Research Laboratory, K. H. Norris; Organic Chemicals Synthesis Laboratory, J. R. Plimmer; Florist and Nursery Crops Laboratory, H. M. Cathey; Plant Stress Laboratory, M. N. Christianson; Plant Physiology Institute, H. R. Carns); Gainesville, Flordia (L. A. Allen, Jr.); Peoria, Illinois (Northern Regional Research Center, M. E. Slodki); Ames, Iowa (National Animal Disease Center, G. W. Pugh); Las Cruces, New Mexico (Jornada Experimental Range, W. B. Sisson); and the U.S. Forest Service at Fort Collins, Colorado (Rocky Mountain Forest and Range Experiment Station, M. R. Kaufman).

Extramural research was conducted at Fort Collins, Colorado (Deparment of Horticulture, Colorado State University, F. D. Moore, III), and at Gainesville, Florida (Department of Fruit Crops, University of Florida, R. H. Biggs).

RESEARCH PROGRESS

Development of Instrumentation for Measuring UV-B Radiation

One of the most significant accomplishments made during the past year in support of the interagency BACER program was the development of improved instrumentation for monitoring and measuring UV-B radiation.

The Instrumentation Research Laboratory at Beltsville, Maryland, designed, constructed, and successfully tested an automatic UV spectroradiometer capable of measuring UV radiation every nanometer (nm) from 250 to 400 nm with a wavelength sensitivity of 0.1 nm (or 1Å). This sensitivity is necessary to detect small changes in UV radiation since a one-nm change in UV radiation is equivalent to approximately a 16 percent change in ozone concentration.

Significant design features of this instrument include: a single or double monochromator with holographic gratings; a variable-speed-motor drive to scan the entire UV region in less than 5 minutes; a specially designed teflon bubble diffuser for cosine correction of the incoming UV radiation; a solar blind filter or a solar blind phototube; and an amplifier output digitized with a digital voltmeter which is interfaced with a desk-top programmable calculator.

As the spectrum is scanned, the programmable calculator corrects the measured signal for instrument calibration and prints out the absolute spectral irradiance of the UV source being measured. The calculator also controls the operation of the spectroradiometer so that, on command, scanning is begun and readings are recorded for each nanometer interval. The calculator prints out the wavelength and spectral irradiance for each wavelength interval, sums the absolute and biologically effective UV radiation (based on a programmed action spectra) for desired band widths and, at the end of each scan, reverses the wavelength drive and returns the monochromator to the starting wavelength. At the completion of the scan, the data can be stored on a magnetic tape for future analyses or transferred to an automatic plotter. A miniature low-pressure mercury-arc lamp is used to provide a precise check of wavelength sensitivity. The calculator computes the position of the 253.7-nm and the 296.7-nm mercury lines to a precision of ± 0.01 nm.

In order to provide investigators in the program with a simple instrument for monitoring the output of artificial UV sources in laboratory, greenhouse, and growth chamber studies, broad-band and narrow-band UV radiometers were also developed by the Instrumentation Research Laboratory. These instruments include a teflon bubble cosine receptor, a solar-blind phototube, a battery-powered photometer circuit and a small rugged housing. In order to provide a basis for inter-laboratory comparisons of UV data, the sensitivity of the broad-band radiometer was adjusted to give the same full scale reading under a common UV source (FS 40 fluorescent sunlamps filtered with 0.013 cm cellulose acetate). Correction factors were developed for use under other lamp-filter combinations.

The specifications for these instruments were made available to industry, and commercial models have now been developed and obtained by cooperating locations.

Spectral Characteristics of Fluorescent Lamps and Testing of Weighting Functions

The Agricultural Equipment Laboratory at Beltsville, Maryland, developed mathematical equations describing the distribution of normalized UV irradiance levels in any desired combination of lamps, either parallel or end-to-end, at any defined distance of the lamps from the illuminated surface. A computer program was written which permitted scientists to accurately design biological experiments and interpret the results.

Lamp fixtures were fitted with specially designed reflectors to provide greater uniformity and reproducibility in UV radiation experiments. Multiple fixture assemblies were designed and built.

An average or standard spectral distribution of UV energy of the sun for the middle Atlantic area was derived from data collected by the Smithsonian Radiation Laboratory, Rockville, Maryland, in June-July 1976, and by the Instrumentation Laboratory, Beltsville, Maryland. This is now being used by Beltsville scientists as a base for design of UV enhancement experiments.

In conjunction with the Florist and Nursery Crops Laboratory and the Plant Stress Laboratory, experiments with higher plants were undertaken to more clearly define the weighting function that must be used to interpret results since the spectral distribution of the fluorescent lamps do not duplicate that of the sun. Several weighting functions were investigated. The equation providing the best fit was derived and is being used by the majority of investigators. We are continuing to obtain data testing the applicability of this weighting function.

Biological Effects of UV-B Radiation on Plant Growth and Function

Greenhouse, growth chamber, laboratory and field studies were conducted by the Plant Stress Laboratory at Beltsville, Maryland, on a wide range of vegetable and agronomic crops to determine the relative sensitivity or resistance to increased UV-B radiation. Data were collected on various physiological responses to increased UV-B radiation including: photosynthesis, respiration, ion uptake, translocation of radioisotopes, stomatal activity, changes in chlorophyll and anthocyanin content, leaf movement, germination, seedling growth and reproductive development. Studies were also conducted on UV-B interactions with disease organisms.

Broad-band UV-B studies were conducted in the greenhouse and growth chamber on over 20 species and cultivars of vegetable and agronomic crops. Plants were exposed to a gradient of UV-B radiation representing a 50 to 500 percent increase in biologically effective UV radiation. Plants studied included cotton, peanut, wheat, rice alfalfa, cucumber, pea, beet, tomato, rutabaga, okra, bean, radish, and turnip. Most

plants were exposed to UV-B for 4-5 weeks from time of planting the seed, but a few (wheat, rice, alfalfa, cotton) were grown to maturity under elevated UV-B. Visual injury was observed in over half of the species and cultivars studied. In most cases only slight or moderate UV damage was noted even when the plants were exposed to an increased level of biologically effective UV radiation as high as 300-400 percent.

The most dramatic evidence of UV-B injury was chlorosis in pea and cucumber, necrosis in pea leaves and pods, and reduction in leaf size in pea and cucumber.

Dose-response studies conducted on cucumber varieties demonstrated significant differences in UV-B sensitivity; Poinsett cucumber was extremely sensitive and Ashly cucumber was only slightly sensitive. Evidence was obtained for UV-B induction of chlorosis of the leaves, inhibition of leaf enlargement, and reduction in biomass. These effects were most pronounced under conditions of low photosynthetically active radiation, and high UV-B exposure.

High levels of UV-B irradiation in the greenhouse (100-400 percent increase in biologically effective UV) reduced the total number of kernels in Pacific Triple Dwarf wheat by 20 percent, but had no appreciable effect on the average weight of grain.

Translocation of radioactive zinc from the cotyledons to other plant parts of the young cotton was not influenced by a 100-400 percent increase in biologically effective UV; however, the transport of radioactive calcium was depressed 12-30 percent over this range of UV irradiation.

Based on linear regression analysis of plant data obtained in the greenhouse of one of the more sensitive plants (Poinsett cucumber) exposed to increased UV irradiation (from 50-300+ percent increase in biologically effective UV), it was estimated that a maximum decrease in stratospheric ozone content of 20 percent would cause a 10 percent reduction in dry matter accumulation and a 15 percent decrease in leaf area. It is not possible at the present time to determine whether these estimates can be applied to other species of higher plants.

Measurements were made on net photosynthesis rates, plant biomass production, stomatal diffusive resistance, and transpiration rates in selected plants of snap bean, clover, cotton, cucumber, and wheat irradiated in the greenhouse and growth chamber. In general UV-B effects on net CO_2 exchange rates and foliar gas exchange were correlated with the amount of visible injury induced.

Chromatography and subsequent UV-VIS spectroscopy of acidic methanol extracts of <u>Coleus blumei</u> leaves taken from UV-B irradiated plants demonstrated a degradation in UV absorbing compounds. Similar results were obtained with reflectance measurements. Increasing the UV-B irradiance resulted in increased degradation of anthocyanin pigment, reduction in the rate of leaf expansion, inhibition of apical growth, and abnormal development of the leaves.

Field studies were conducted on UV effects at Beltsville/on a range of agronomic and vegetable crops using a gradient of UV radiation developed by the ARS Agricultural Equipment Laboratory. Crop plants studied included Contender bush bean, Early Prolific straightneck yellow squash, Amsoy-71 soybean, sugar beet, Golden Cross Bantam corn, R-720 sorghum, and Waltham 29 broccoli. A fall crop of winter grains was also grown that included Potomac, Redcoat, and Abe wheat, Pennard and Monroe barley, and Abruzzi rye.

Increasing the biologically effective UV radiation by 100 percent had no visible or consistent effect on crop performance under field conditions, but statistical analyses of the data have not been completed.

Plant Disease Interaction with UV-B Radiation

The Plant Stress Laboratory at BARC has studied the effects of UV-B radiation on plant diseases. The results of increased levels of UV-B irradiance on spore germination indicate that although plant leaf pathogenic fungal species vary considerably in sensitivity to UV-B, relatively high irradiance levels are required to reduce germination percentage. Pigmented spores such as *Cladosporium*, *Stemphyllium*, and *Alternaria* were found to be more resistant to increased UV-B irradiance than hyaline spores (*Mycosphaerella*, *Colletotrichum*).

Disease severity of *Colletotrichum lagenarium* on cucumber was decreased with increasing UV-B irradiances. A linear decrease in the percentage of leaf area diseased with increased irradiances was found.

Increased levels of UV-B irradiance did not affect disease severity of *Cladosporium cucumerinum*. The disease tended to reduce plant growth equally regardless of UV-B irradiance levels.

There were no noticeable UV-B effects on either the *Stemphyllium botryosum* pathogen or the host, alfalfa.

In summary, recognizing that our results represent only a small sampling of leaf disease organisms and of plant disease-interaction experiments, they appear to support the following: (1) considerably higher levels of UV-B irradiances than those expected from the projected ozone depletion will be required to adversely affect germination and growth of pathogenic fungi, and (2) where fungal germination and growth are affected, disease severity in the host plant can be expected to be reduced as UV-B irradiances increase.

Response of Florist and Nursery Crops to Increased UV-B Radiation

Greenhouse and growth chamber studies were conducted by the ARS Florist and Nursery Crops Laboratory at Beltsville, Maryland, on a wide range of florist and nursery crops to determine their relative sensitivity or resistance to increased UV-B radiation. Selected plants were also chosen for reflectance and fluorescence measurements and for microscopic examination in the laboratory. After 2-8

weeks of exposure, visible injury was observed in eight of the 58 species irradiated, and then only when applied in excess of projected levels of UV-B radiation expected to result from CFM-catalyzed reduction of stratospheric ozone reduction.

The most typical response to high levels of UV-B irradiation (100 percent or greater increase in biologically effective UV) included breakdown of chlorophyll and anthocyanin and a glazing and browning of the tissue, generally attributed to the presence of oxidized, polymerized, phenolic compounds. Other effects observed in some of the test plants included abnormal leaf growth, characterized by reduced size, twisting and distortion, and reduced plant height. Plant biomass was generally unaffected when mature plants were irradiated; biomass of young seedlings, however, was frequently depressed under high UV-B.

There was considerable variation in sensitivity to UV-B exposure, depending upon species and cultivar, stage of development, time of year, and level of exposure. In general, herbaceous plants were more sensitive to increased UV-B than were woody plants. *Fatsia japonica* was the only woody species of the 10 tested that showed inhibitory effects of high UV-B.

Plants irradiated during the summer months in the greenhouse showed little or no UV injury, even under the highest levels of UV-B used. This was in sharp contrast to the spring and winter months when they showed considerable injury under the same level of UV irradiance.

Poinsettia, *Coleus*, and *Browallia* were among the most sensitive examined. Other species sensitive to increased UV-B irradiation included aster, hollyhock, vinca, and impatiens.

In order to develop a capability for understanding the basic cellular and ultrastructural mechanisms of UV-B effects, a UV microspectrophotometer was obtained and assembled in the Florist and Nursery Crops Laboratory. This instrument will enable ARS researchers to irradiate single cells or cellular constituents as small as 0.5 μm with narrow band UV radiation, to make rapid scans of absorbance and reflectance in the region of 250-1000 nm, and to make precise measurements of UV fluorescing materials. A programmable calculator was also obtained to control the instrument and to provide on-line data acquisition, processing, storage, and display.

Influence of Solar UV-B Radiation on Crop Productivity

Greenhouse, growth chamber, and field studies were conducted by the Fruit Crops Department, University of Florida, Gainesville, Florida, (under contract to ARS), on a wide range of vegetable and agronomic crops to determine their relative sensitivity or resistance to increased UV-B radiation.

Field studies were conducted at Gainesville under specially constructed UV-B gradients obtained by mounting the fixtures at an angle over raised plant beds. Crops grown to marketable size and maturity included corn, potatoes, tomatoes, field peas, peanuts, rice, squash, mustard, and radish. Although statistical analyses of the data have not been completed, visual effects were observed in corn and rice under high UV-B irradiances (100 percent or greater increase in biologically effective UV). Both crops appeared dwarfed and the grain head of the rice plants were slower to mature than the unirradiated controls.

Growth chamber studies were conducted by University of Florida researchers at the Phytotron at Duke University in Durham, North Carolina. Over 100 species and varieties of agronomic, horticultural and forest plants were grown from seed for 4-12 weeks under increased UV-B radiation. Under high levels of biologically effective UV-B radiation (100 percent or greater increase) plants exhibited a number of abnormal responses. These included: marginal and interveinal chlorosis; cupping and epinasty of the leaves; changes in pigmentation; increased branching; reduced vineness; and reduction in height, leaf area, and biomass.

In general, plants within the same family responded similarly to increased UV-B radiation. By using controlled environment studies it was possible to identify varieties of soybeans that are sensitive to present levels of UV-B radiation at Gainesville, Florida.

Preliminary studies conducted in the Phytotron with Jori wheat and Hardee soybean, at 4 levels of UV-B radiation and 4 levels of visible radiation showed that the extent of UV-B radiation damage was greatly influenced by the amount of visible radiation present. Other research accomplishments of the University of Florida scientists included developing an action spectrum for pigment induction in the avocado leaf having a maximum effectiveness in the UV-B region at 295 nm. These investigators also found that increasing the level of biologically effective UV radiation by up to 100 percent had no significant effect on structural changes or chemical composition of surface waxes of tomato and pepper plants. Agronomic plants subjected to high levels of UV-B radiation also produced increased amounts of ethylene and accumulated large quantities of abscisic acid than control plants.

<u>Response of Vegetable Crops to High UV-B Radiation at High Elevations</u>

UV-B enhancement and exclusion studies were conducted by the Department of Horticulture, Colorado State University at a 3000 m site elevation in the Rocky Mountains.

Supplementing natural solar radiation with additional UV-B radiation had no significant effect on the growth and biomass of pea, radish, potato, and wheat grown at this elevation. Shielding wheat plants from natural solar UV-B, however, resulted in an increase in size of the plants.

Other accomplishments included the development of transmission spectra for a chlorinated-fluorinated resin film "Aclar" found to be useful in aquatic studies as a UV transparent film; development of an assay for detecting loss of electrolytes from UV-irradiated plant tissues; characterization of the influence of low temperatures on decline in lamp output of UV fluorescent sun lamps; and design of a solar UV-B collector and irradiator.

Response of Arid and Semi-arid Plants to Increased UV-B Radiation
ARS scientists at Las Cruces, New Mexico, investigated selected native and economically important species indigenous to the arid southwest United States. Plants were exposed to increased UV-B irradiation in the greenhouse. Dose response studies were conducted on alkali sacaton (*Sporobolus airoides* Torr.), mesa dropseed (*S. flexuosus*) and Chile pepper (*Capsicum frutescens*). Alkali sacaton and Chile pepper plants exposed to high UV-B showed a marked reduction in leaf growth with increasing UV-B. Mesa dropseed plants, however, showed no differences in leaf growth between UV-B-irradiated and control plants. Dock plants (*Rumex patientia* L.) exposed to high levels of UV-B showed a reduction in protein synthesis.

Impact of Solar Radiation on Crops and Crop Canopies
Physiological and ultrastructural studies were conducted by ARS researchers at Gainesville, Florida, on selected vegetable, agronomic and citrus crops exposed to increased UV-B radiation in the field and the greenhouse.

Citrus plants irradiated for 4 weeks under supplemental UV-B radiation in the field showed no significant reduction in average daily photosynthetic rate as compared with unirradiated control plants even under a 200 percent increase in biologically effective radiation. Similar results were obtained in stomatal diffusion resistance of eight soybean varieties.

Broad band UV-B enhancement studies were conducted in the greenhouse on soybeans ('Bragg' and 'Altona'), peas ('Little Marvel'), tomatoes ('Rutgers') and sweet corn ('Golden Cross Bantam'). Plants were grown for 4-6 weeks under three levels of UV-B irradiation ranging from approximately a 100-200 percent increase in biologically effective UV. Data were taken on biomass, CO_2 uptake rate, chlorophyll content, Hill reaction, RuDP carboxylase, PEP carboxylase, soluble proteins, absorption spectra of pigment extracts, and ultrastructural changes in selected cultivars.

In general, plants exposed to high UV-B irradiation in the greenhouse showed physiological changes. For example, soybean plants showed a decrease in chlorophyll content, RuDP carboxylase activity, soluble protein content, CO_2 uptake, and fresh and dry weight as compared to control plants receiving only UV-A (320-400 nm) irradiation alone or unirradiated control plants. In contrast, plants given supplemental UV-B irradiation in the field showed little or no effect.

Differences in species and cultivar response to increased UV-B irradiation were also observed. Differences in chemical and structural makeup of the epidermis and palisade parenchyma cells were thought to play a role in the response of different plants to enhanced UV-B radiation.

Response of Woody Plants to Increased UV-B Radiation

Various physiological disorders of agronomic and horticultural crops and woody species have been ascribed to high levels of solar irradiation, especially at high elevations. In order to determine the role of UV-B radiation in solar injury of certain woody plants at high elevations, Forest Service scientists conducted UV-B enhancement and exclusion studies at the Rocky Mountain Forest and Range Experiment Station in Fort Collins, Colorado. Englemann spruce was chosen as a sensitive species and Lodgepole pine was chosen as a resistant species.

Seedlings were irradiated under artificial UV lamps for a total of 400 hours over a 67 day period or were grown under various filters to exclude natural UV-B radiation. No evidence of UV injury was observed in any of the treatments during the first year of the study. Since Engelmann spruce seedlings transplanted to the natural environment do not show symptoms of solar radiation injury until after the first winter, seedlings will be observed for symptoms during the second growing season.

Response of Nitrogen-fixing Organisms to Increased UV-B Radiation

Nitrogen fixation of *Anabena* floss-aquae and other blue-green algae, free-living and in symbiosis with the water fern *Azolla*, is important in rice culture and in worldwide soil fertility. Laboratory studies were, therefore, conducted at the ARS Northern Regional Research Center in Peoria, Illinois, on the influence of increased UV-B radiation on the nitrogen fixing abilities of *Anabena* alone and in association with *Azolla*.

Preliminary results indicated that while viability and photosynthesis of *Anabena* cells were unaffected by UV-B irradiation, nitrogen fixation (as measured by nitrogenase activity) was markedly reduced by high levels of UV-B irradiation.

When cultures of blue-green algae were exposed to 10 watts/m^2 of UV-B for 3-5 hours the agal nitrogenase was inhibited to about one-half of the activity of the control cultures. In spite of this observed reduction in nitrogenase activity there was no reduction in the treated cell's reproductive capacity as demonstrated by plate count studies.

When blue-green algae and its symbiont *Azolla* were exposed for 4-6 days with 10 watts/m^2 of UV-B, photosynthesis ($C^{14}O_2$ fixation) was not affected, and nitrogenase activity was reduced to 30-40 percent of that observed in the control.

Response of Farm Animals to Increased UV-B Radiation

Studies conducted by ARS researchers at the National Animal Disease Center in Ames, Iowa, investigated the carcinogenic effect

of high levels of UV-B irradiation on the eyes of 4 Hereford cattle. Exposing eyes of these cattle to high levels of UV-B irradiation for 2 hours per day induced ocular changes that were consistent with chronic irritation. After 7 months of exposure, 1 animal developed ocular changes that were considered neoplastic after biopsy and pathological examination. "Cancer eye," a squamous cell carcinoma, normally takes 5-6 years to develop in cattle under natural conditions.

Inspection of slaughterhouse condemnation records was made to determine the extent and incidence of "cancer eye" in cattle, using USDA Meat and Poultry Inspection data. Based on the total cattle slaughtered since 1950 the increase in "cancer eye" was about 2-fold. Since other diseases of cattle have also increased during this time period, it is difficult to interpret these data.

Response of Insects to Increased UV-B Radiation

Studies were conducted in the ARS Chemical and Biophysical Control Laboratory at Beltsville, Maryland, on the influence of increased UV-B radiation on the physiology and behavior of selected beneficial and harmful insects. These studies demonstrated that lightly pigmented insects, such as the pink bollworm, codling moth, and the face fly, were much more sensitive to exposure to UV-B irradiation than heavily pigmented ones such as the house fly.

Brief exposures of pink bollworm eggs to UV-B radiation levels (10-50 percent above natural levels at Beltsville), for 1 to 3 hours greatly reduced the life span of larvae hatching from these eggs. High UV-B levels (100 percent increase in biologically effective radiation) also had a highly lethal effect on face fly pupae irradiated for 1 hour per day for 3 days.

Adult honey bee workers, however, were able to tolerate a 10-50 percent increase in UV-B radiation for 6 hours per day for 6 days without apparent injury.

High UV-B irradiation increased pigment formation in the larvae of butterflies and moths, and the pupae of face flies, but had little or no effect on the pigment content of tobacco budworm larvae, house fly pupae, or honey bees.

Physiological studies on respiration indicated an increase in oxygen uptake in codling moth larvae irradiated 6 hours per day for 2 days, but no effect on honey bee workers.

Tobacco budworms allowed to feed on bean leaves exposed to UV-B irradiation did not show increased mortality. The eggs of pink bollworms, however, irradiated on cotton leaves showed a reduction in number that hatched.

Stability of Agricultural Chemicals Under Increased UV-B Irradiation

The ARS Organic Chemical Synthesis Laboratory at Beltsville, Maryland, constructed and successfully put into operation a "merry-go-round"

type photolysis apparatus for investigating the stability of pesticides and other agricultural chemicals under increased UV-B irradiation. Such studies are being conducted to determine the efficacy of various agricultural chemicals under a high UV-B environment.

Photodegradation of test compounds was obtained by exposing the samples to 313 nm radiation in the UV-B region and quantum yields measured. Preliminary studies with aqueous solutions of pesticides confirmed the dependence of quantum yield (the number of pesticide molecules consumed per quantum of UV-B radiation absorbed) upon concentration.

RESEARCH FUNDING LEVEL

Funds were made available during FY 1977 by EPA, ARS, FS, and Universities. Amounts furnished by each and allocation to specific research projects are shown in Table 1. Information on funding for continuation of these research efforts beyond January 31, 1978, is not available at the time of writing of this report.

Table 1. Funding of USDA BACER Program to January 31, 1978

	USDA Commitment			University Commitment
	ARS		Forest Service	
	In-house Funds	EPA Pass-through Funds		
Funds to September 30, 1977 (FY-77)				
Beltsville Agricultural Research Center				
Agricultural Equipment Lab	67,290	54,722	-	-
Chemical and Biophysical Control Lab	18,707	47,882	-	-
Instrumentation Research Lab	26,916	85,276	-	-
Organic Chemicals Synthesis Lab	19,228	35,000	-	-
Florist and Nursery Crops Lab	30,954	69,770	-	-
Plant Stress Lab	71,866	218,885	-	-
Plant Physiology Institute	24,090	86,834	-	-
Gainesville	34,687	40,000	-	-
National Animal Disease Center	46,460	34,200	-	-
Northern Regional Research Center	12,993	35,000	-	-
Las Cruces	12,761	35,000	-	-
Fort Collins	-	40,000	36,716	-
ARS Administrator's Contingency	50,000	-	-	-
ARS Administrator's Reserve	250,000	-	-	-
EXTRAMURAL				
Colorado State University	-	50,431	-	18,700
University of Florida	-	145,000	-	53,700
FY-77 TOTALS	665,952	978,000	36,716	72,400
Funds for October 1, 1977 through January 31, 1978 (FY-78)				
	136,466	-	9,222	-
FY-77 and FY-78 TOTALS	802,418	978,000	45,938	72,400

RECOMMENDATIONS FOR LEGISLATION AND/OR REGULATION FROM THE SECRETARY OF AGRICULTURE TO THE ADMINISTRATOR OF THE ENVIRONMENTAL PROTECTION AGENCY AND THE CONGRESS OF THE UNITED STATES

The U.S. Department of Agriculture has supported continuing research programs to establish scientific knowledge on the effects of changes in the ozone in the stratosphere upon animals, crops, and other plant life. Because of the demonstrated significance of increase UV-B radiation on economic plants and animals (and on some agricultural chemicals), and due to potential effects of stratospheric ozone depletion on climate with potential impacts on agriculture, it is recommended that there be continuing dialogue and communication among regulatory agencies, the legislative branch, and the USDA, especially its research group. Therefore, USDA data are presented to the Administrator of the Environmental Protection Agency so that he may use this knowledge as a base for recommendations for legislation and/or regulation concerning this issue.

The Department is concerned about reports alleging that nitrous oxide, arising from use of nitrogen fertilizers in agriculture, ultimately reduces the stratospheric ozone levels. Therefore, the Department recommends that full attention be given to all currently available research results, as well as those yet to be obtained, before regulatory decisions and legislative actions are taken on this matter.

The Department also recommends that there be continuing research to investigate the responses of plants and animals to increase levels of ultraviolet radiation resulting from changes in stratospheric ozone concentrations alleged to be caused by release of chlorofluoromethanes, nitrogen oxides, and perhaps other substances.